HARDING UNIVERSITY

Single Player Against Machine BAttleship Game

Mid-Term Progress Report

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March 3, 2010

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Single Player Against Machine BAttleship Game (SPAMBAG)

Requirements Specification

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OVERVIEW:

Battleship is a classic game that many people play in their childhood. Typically, it is a two player game where one person plays against another. We are recreating this game so that one person can play by themselves against an interactive computer that has a robotic piece placement device. This allows a novice player to get a feel for the rules and potentially develop and improve strategies of their own. Aside from the inputs from the player on where he/she wants to place his/her ships and target the computerôs ships, the game is hands free.

OPERATIONAL DESCRIPTION:

Our battleship game will follow all of the standard rules of the classic battleship game. There will be a user input-interface, most likely an interactive LCD screen that will prompt the user with instructions and notifications, such as when to make a move or indicate when the player sunk one of the computerôs ships. There will also be a keypad which will accept the coordinates of the playerôs moves. Beginning game play will require the player to physically place his/her ship pieces on the lower display. Once the playerôs ships have been placed, the game begins a random selection of who (player or computer) goes first. This selection will be indicated on the LCD screen. On his/her turn, the player inputs his/her move. The microprocessor then discerns if the input was a hit or miss and gives the corresponding output on the upper display. Outputs include lighting a red LED (hit) or a green LED (miss). On the computerôs turn, it makes a move, the microprocessor discerns a hit or miss, and shows its output on the lower display by placing a red (hit) or green (miss) ball via the ball manipulator into its respective spot. This process is repeated until the game is over.

DELIVERABLES:

- Userôs Manual
- Software Logic Flowchart
- Technical Drawings and Analysis of Hardware
- Schematic of Circuit with Simulation Results
- Documentation of Testing
- A Final Report
- Parts List with Budget
- Battleship Game

DRAFT USER MANUAL:

Setup:

- Remove the game from its package
- Open the lid for the game
- Plug in the power cord to a Type B NEMA 5-15 15 A/125 V grounded outlet.
- Separate the balls by color and load them into the containers.
- Turn on the game by flipping the ON/OFF switch located on the board.

Operation:

1. Physically place the ship pieces on the lower display board so that the holes in the piece correspond to holes in the board.
    - For the aircraft carrier (five cells).
    - For the battleship (four cells).
    - For the cruiser (three cells).
    - For the submarine (three cells).
    - For the destroyer (two cells).
2. Wait for the computer to choose the location of its ships as indicated by the LCD screen located in the upper display of the game.
3. If the LCD screen indicates that it is the playerôs turn, select coordinate of attack (a space on the grid you believe the computerôs ship is). If the LCD screen indicates that it is the computerôs turn, continue to step six (beginning of game only).
4. Enter the coordinate on the keypad by selecting the letter (A-J) that corresponds to the chosen location and then select a number (1-10) that corresponds to the same location.
5. Notice the LED light up which indicates that the coordinate selected in step 3 was either a hit (red) or a miss (green).
6. Wait for the computerôs turn.
7. The attack of the computer will be recorded by dropping a ball on the lower display. The ball will be red if it coincides with the location of one of your ships; it will be green if it is a miss.
8. Repeat steps three through seven until the game is completed as indicated by the LCD screen.
9. Select the option to play a new game if desired and repeat steps one through eight or turn off the device using the ON/OFF switch on the lower display.
10. Unplug the game from the outlet.

USER INTERFACE:

The user interface will consist of an ON/OFF switch that allows the system to be turned on and off. There will also be ship pieces for the user to physically place on the lower display board to indicate the location of the userôs ships. There will be a keypad that will act as an input receiver for the userôs moves and will also have keys for the player to indicate if the computer sunk a ship. Also included is an interactive LCD screen that will prompt the user when it is their turn, whether they hit or missed the computerôs ship, and other instructions throughout the gameplay.

CAPABILITIES:

- Will have artificial intelligence for the computer to choose locations close to a hit in order to sink the userôs ship. Once two hits are found, only locations along a straight line should be attempted until a sinking takes place as confirmed by the user via the keypad. When the user indicates which ship has been sunk via the keypad, the computer will determine if it hit another ship in the process. If so, the computer will continue selecting coordinates in the area until it sinks that ship. Once the computer determines that there are no more known ships in the area, it will continue selecting random coordinates of attack.
- Will be able to be operated and moved by one person.
- Will acknowledge whether the coordinate selected corresponds to either a hit or a miss by displaying a message in the LCD screen and lighting up the LED in the upper display of the game that corresponds to the coordinate selected by the user. If it is a hit the color of the LED will be red and if it is a miss it will be green.
- Will be able to setup in no more than 5 minutes.
- Will be able to place balls of different colors to different locations on the board in no more than 20 seconds per move.

TESTING:

Ball Manipulator Test / Motor Test: To test the ball manipulator and the motors, a full mechanical system test will be performed where a test program is run and tells the ball manipulator to place one ball in every possible location (A1-A10 though J1-J10) in order. The test will be considered successful if the mechanical device arrives at the correct coordinate every time and if the ball makes it to the coordinate without dropping prematurely 99 out of 100 times the movement is done. This test will be run five times and statistical analysis will be performed on the results. If the ball drops prematurely, the user can place the ball in the correct location as displayed on the LCD screen.

Portability Test: To determine portability and ease of operation by one person, three volunteers not associated with the Senior Design class will move the device to a testing room where outlets are available and will follow the setup and operation as described in the userôs manual. Feedback will be gathered from the volunteers via a survey to determine if the device is portable and through observation if it is easily operated. The game will weigh no more than 22.73 kg (50 pounds) and will take up a volume no more than 1.0 m^3. The footprint of the device will be no more than 1.0 m^2 and its depth no greater than 1.0 m.

LEDs Test: To test the proper functioning of the LEDs, the program will be written so that every possible location corresponds to a hit. Then, a tester will key in values for all one hundred locations. The program will reset the board and repeat the process so that all locations correspond to a miss. Only one LED must be lit whenever a coordinate is entered and should be either green (miss) or red (hit). If only one LED lights up for each entry and corresponds to the correct color, the LED test will be considered a success. Also, there will be a question on the survey for the volunteers that asks how easily the LEDs were seen.

Artificial Intelligence Test: To test the artificial intelligence of the computer, following a hit, it must continue choosing coordinates in the immediate proximity of the hit. Once two hits are found, only locations along a straight line should be attempted until a confirmed sinking takes place. Also, if it is known that a particular ship has been sunk, the computer will not attempt to re-sink that battleship. Once sunk, the computer may choose a random location of attack based on an externally programmed algorithm. The AI will be tested by playing the game.

Project Overview and Status

Our goal is to create an essentially hands-free version of the classic Battleship® game. The game will be powered through a standard 110 VAC household outlet. There will be a keypad that will receive input such as accepting the coordinates of the player's moves. Also, there will be an LCD screen that will provide feedback to the user and will prompt the user with instructions and notifications, such as when to make a move or indicate when the player has sunk one of the computer's ships.

The major accomplishments that have been reached this semester include the cutting of all Plexiglas pieces, the construction of the motor carts, the boring out of the gears to ensure that they can be securely attached onto the stepper motors' shafts, bread-boarding of the power circuitry, learning to use the software for CNC programming, the modification of the design of the power circuit, and the learning of the implementation for the programmer and the microcontroller.

Though we have reached many of our goals on time, we are making less progress than anticipated. This time delay is due to the change of some modules of the project to ensure the creation of a prototype that meets our requirements specification. Because the ship sensor module and LED module have changed significantly and the original spring schedule was done with a lack of knowledge of the remaining tasks to be completed, an updated schedule for the spring semester has been developed. This new schedule includes much more detail of the specific parts of each module that need to be completed. This will allow us to continue with the building and testing phases and complete the integration of the individual modules of our project on time. The fabrication of the gear racks, uploading of working code into the microcontroller, and PCB design of the LED array and digital logic have been our biggest roadblocks. These roadblocks were caused mainly by the lack of knowledge of the CNC programming language and functioning of the microcontroller and programmer and the complexity of the digital logic. The difficulty of the programming and the uploading of the code were underestimated. On the other hand, we have been able to make good progress on areas such as: sensing system, gears, LCD screen and construction of the frame. The changes and current status of our project will be discussed in detail in this report.

As we continue in the assembling and testing phases of our project, there are still some changes that will need to be made for our Battleship game to operate in the way it is intended. These areas will most likely be in the frame measurements, attachment of the sensing system onto the overall movement system and the PCB layouts. Over the next few weeks, the gear racks will be fabricated, frame assembly will be complete, and the code will be uploaded into the microcontroller. These accomplishments will enable us to continue with the assembling and testing of the independent modules for them to be integrated into the overall project.

Accomplishments

LCD Screen

The LCD screen has sixteen wires that send power and signals that run the screen according to the specifications sent from the manufacture. While soldering wires to the circuit board for our LCD screen, one of the solder pads was damaged causing complications in operation during testing. After finding the issue with the damaged solder pad, it was able to be repaired after a difficult process to fix the problem. The working LCD screen is shown in Fig. 1 outputting test values from the program written on our dsPIC30F6015 microcontroller.

Figure 1 – LCD output

In Fig. 2 below, you can see the leads more closely, including the one that was damaged. The pad in the lower right hand corner of Fig. 2 was the one that was damaged. You can see how the wire had to be bent over to the trace in order to solder a connection. Using a microscope and a high quality soldering iron, the precise connection needed for the repair was made.

Figure 2 – Solder pads

The datasheet and other information for the LCD screen used in this project can be found in Appendix K.

Microcontroller

In this project, we went with the dsPIC30F6015 microcontroller from Microchip due the convenience of equipment provided by the school and because of the optimal amount of input/output pins for the projectôs needs. As of right now, we are writing functions for the LCD screen and stepper motors. We have been able to test these devices and they work well. The code that has been written that should print to the LCD and then run the stepper motor continuously can be found in Appendix B.

Figure 3 – MPLAB PM3

The code used to test the microcontroller initially looked like the code below that flashed an LED. The code below did not work however; this was likely due to two possible issues. The first issue with this code was the possibility that the I/O pins were not responding, meaning they were not initialized correctly. The other issue was that the microcontroller was corrupted due to electrostatic damage. These microcontrollers are very sensitive, and since the issue seemed to be the electrostatic damage, additional microcontrollers were ordered so that we have nine. Modifications have been made to how the code is set up and those modifications can be viewed in the test code included in Appendix B.

Test Code

```
#include <p30f6015.h>
// Config directive to set configuration bits

_FOSC(CSW_FSCM_OFF & XT_PLL4);
_FWDT(WDT_OFF);
_FBORPOR(PBOR_ON & BORV_20 & PWRT_64 & MCLR_EN);

#define FCY  7378200                    // 7.37Mhz crystal in 4X PLL mode
#define MILLISEC FCY/7378               // 1 mSec delay constant
```

```
#define   LED1        PORTDbits.RD4          // LED connected to RD4
#define   LED2        PORTDbits.RD5          // LED connected to RD5
#define   LED3        PORTDbits.RD6          // LED connected to RD6
#define   LED4        PORTDbits.RD7          // LED connected to RD7

// Definitions for subroutines

void SetupPorts(void);
void DelayNmSec(unsigned int N);
void DelayMSec(unsigned int N);

int main(void)
{
        SetupPorts();                   // Initialize I/O

        while(1)                        // Do endlessly
        {
                LED2 = !LED2;
                DelayNmSec(200);        // sample keys every 20 mS
        }                               // end of while(1) statement

}                                       // end main

void SetupPorts(void)
{
        PORTD = 0;
        TRISD = 0xFF0F;                 // Set RD7 to RD4 as outputs
}

void DelayNmSec(unsigned int N)
{
        unsigned int j;
        while(N--)
                for(j=0;j < MILLISEC;j++)
                {
                        DelayMSec(20);
                }
}
void DelayMSec(unsigned int N)
{
        unsigned int j;
        while(N--)
                for(j=0;j < MILLISEC;j++);
}
```

After writing working code to the microcontroller, we were able to test it using the TQFP to DIP adapter pictured in Fig. 4 below that was provided by the school. You can also see how the circuit is set up to test the LCD screen and the stepper motor simultaneously. This adapter will be used for testing until the final code has been written to the microcontroller and testing is done. In addition, we are using an NI ELVIS station for power until we have a working power system for the project.

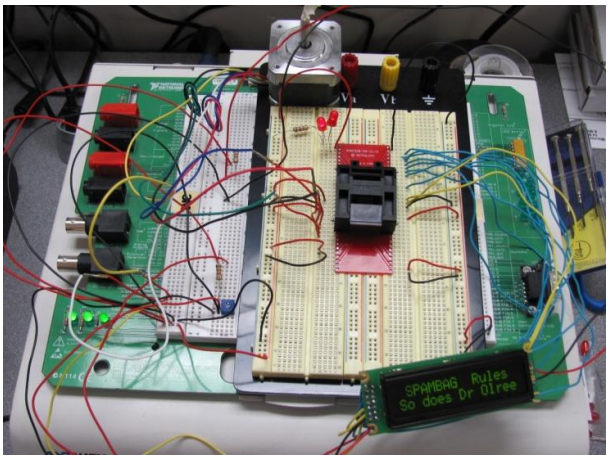


Figure 4 - MCU test circuit

Most of the code will come from the flowcharts which can be viewed in Appendix A (flowcharts) and Appendix B (code). Once all testing of the code is completed and the final version of the code has been loaded to the microcontroller, it will then be attached to a Schmart board. Pictured below in Fig. 5 is the type of Schmart board that will be used in our project. The advantage of this product is that it is an EZ solder product. The solder is already on the board where the leads from the microcontroller make contact, which is optimal for components this small.

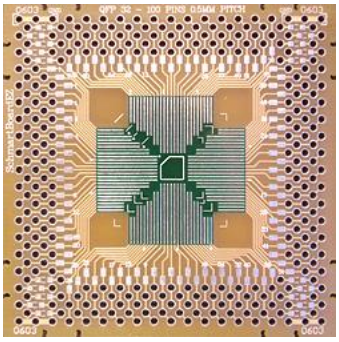


Figure 5 – Schmart Board

The datasheet and other information for the microcontroller used in this project can be found in Appendix L.

Power Supply

The power supply circuit has been modified slightly from its original design. This modification was due to the previous designôs inability to produce a sufficient amount of current to the LED module. In the original design, the power supply was using a series of resistors as a voltage divider but this did not account for the current sinked. Hence, the modification made was the addition of an op-amp as a voltage follower after the needed voltage has been reached by the voltage divider circuit. This op-amp references the voltage outputted from the original design and outputs an equivalent voltage, but the current is drawn through the +Vcc.

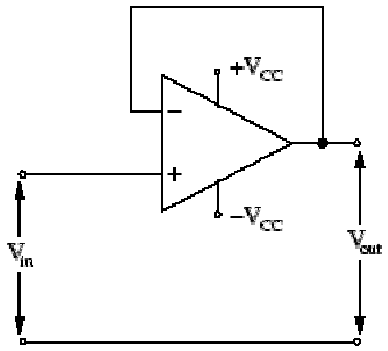


Figure 6 – Voltage Follower Circuit

This eliminates the limit that the original design put on the current drawn from the power supply. The voltage follower is the only major change that has been made to the power supplyôs design.

LED Display and Digital Logic

Similar to the power supply, the LED array has not changed much either. It is still a ten by ten grid of dual color, lead dependent LEDs which accept signals from the digital logic module. The digital logic module has been changed slightly. The modification was necessary because the outputs of the SR latches used are the complement of what was originally expected. To explain, the Q output of the SR latch ôkeep stateô in Multisim happens when the inputs are both low logic signals, but on the SR latch ordered, the ôkeep stateôhappens when both logic input signals are high. The original design was expecting the Q output of the SR latch to be ôkeep stateôwhen the inputs were both low. The modification switch was made to expect the Q output to be ôkeep stateôwhen both inputs are high. To explain furthermore, the difference in the logic for an SR latch is shown in Table 1 and Table 2 below.

S input	R input	Q output
0	0	keep state
1	0	high
0	1	low
1	1	unstable

Table 1 – Multisim SR latch logic

S input	R input	Q output
0	0	unstable
1	0	low
0	1	high
1	1	keep state

Table 2 – Ordered SR latch logic

This initially called for a change from using an AND gate as the logic between the two signals controlling the latch to using a NAND gate. This remedied the discrepancy quite well. Then, it was discovered that the quad SR latch chip had internal AND gates on half of its gates. As highlighted in Fig. 7 below, SR latches 1 and 3 have two S-inputs that are ñANDedò with each other and their output goes through the actual latch but 2 and 4 do not. The two S-inputs on 1 and 3 are the ones which are internally ñANDedò. Fig. 8 shows the SR latch circuit being described.

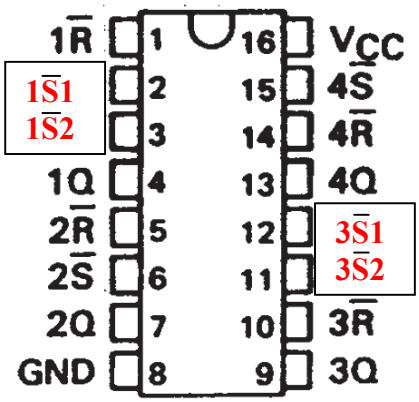


Figure 7 – SR latch Topview

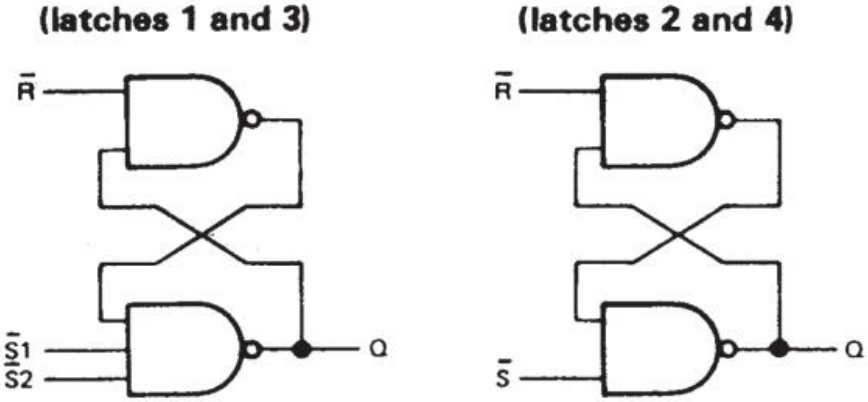


Figure 8 – SR latch circuits

Originally, the AND on these two gates was an asset because it would save money that would have been spent on the AND gates to be placed before it. But, since the design now requires NAND gates instead of AND gates, it has saved nothing. This problem could not be solved by inverting the output because the output was completely internal. In order to adapt to this unforeseen problem, the new design will short the two inputs to those particular SR latches and connect them to an output of an external NAND gate. This leaves these SR latches looking very similar to the ones without the internal AND gate while still having the same functionality.

Fig. 9 below shows the design for the printed circuit board (PCB) without ground and power. These two items will be added over the next day or two. The LED array is located toward the center of the layout and the digital logic is located to the left, right and bottom of the display.

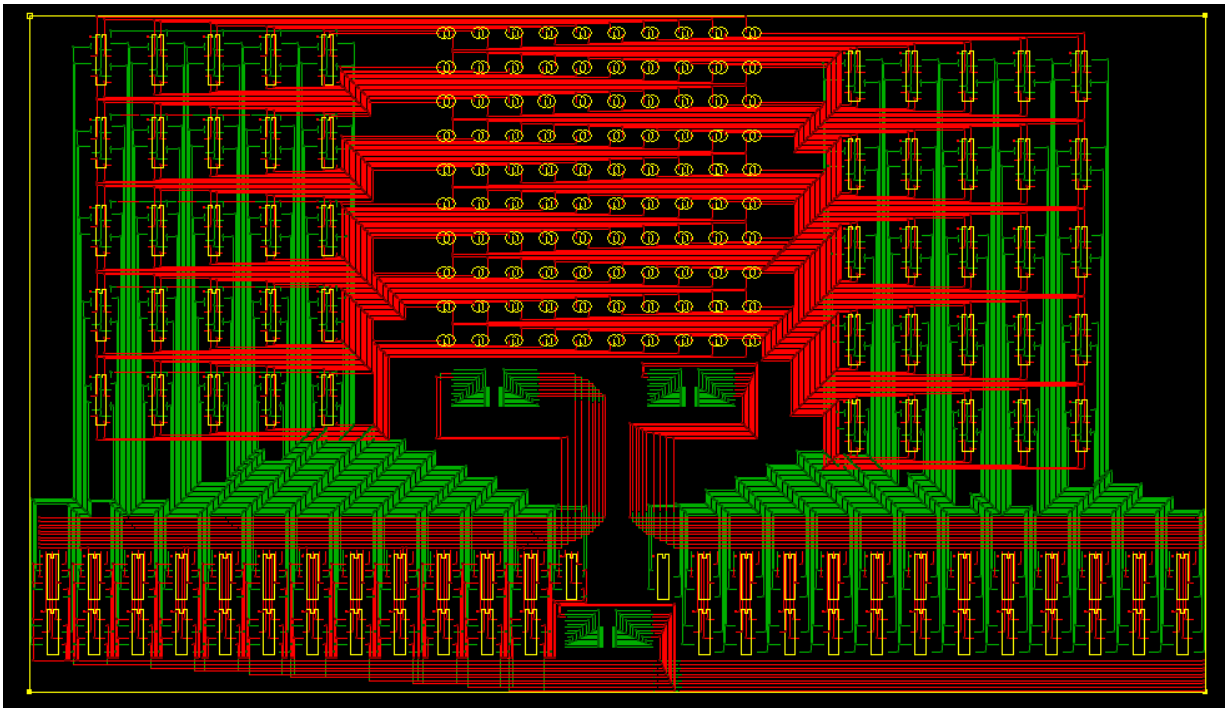


Figure 9 ï PCB Layout for LED Array and Digital Logic

Fig. 10 below is a breadboard mockup of a 3x3 array of LEDôs and the digital logic running them. The LEDôs are easily visible with ambient lighting but the camera was unable to show the contrast of the color to the background well. Fig. 11 is of the same breadboard with the room lights turned off to better display the lit LEDôs in the photo.

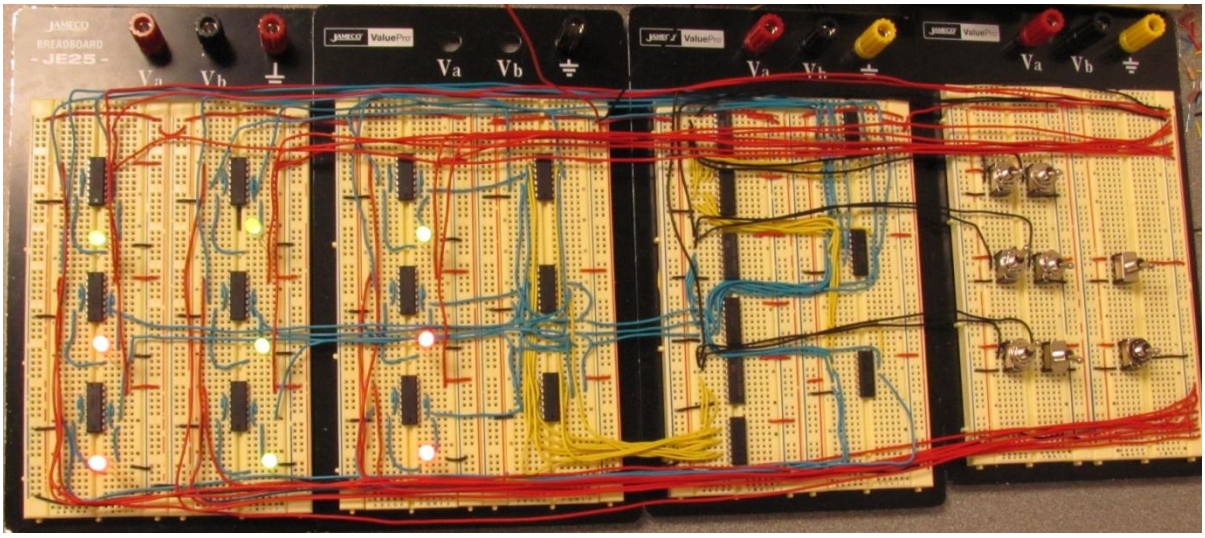


Figure 10 – Breadboard mockup of a 3x3 LED array with digital logic

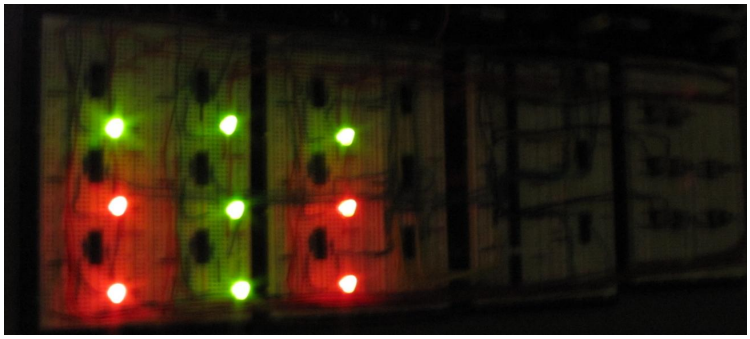


Figure 11 – 3x3 mockup with room lights turned off

Keypad

The keypad design is very straightforward. The original design uses an encoder to accept signals from the keypad and reduces it to a smaller amount. In this project, we use the encoder to encode the twelve decimal inputs to seven binary inputs. Now, instead of the maximum of twelve pins it would have taken on the microcontroller, it will take only seven. The twelve pins would have consisted of one pin for each button on the keypad but the encoder reduces eight of those keys to only three and keeps the other four, making a total of seven.. Unfortunately, it wonôt be able to reduce all of the input lines to four like originally planned, but thatôs only because no encoders could be found to accomplish such a task. Fig. 12 shows the circuit board for the keypad that has been etched.

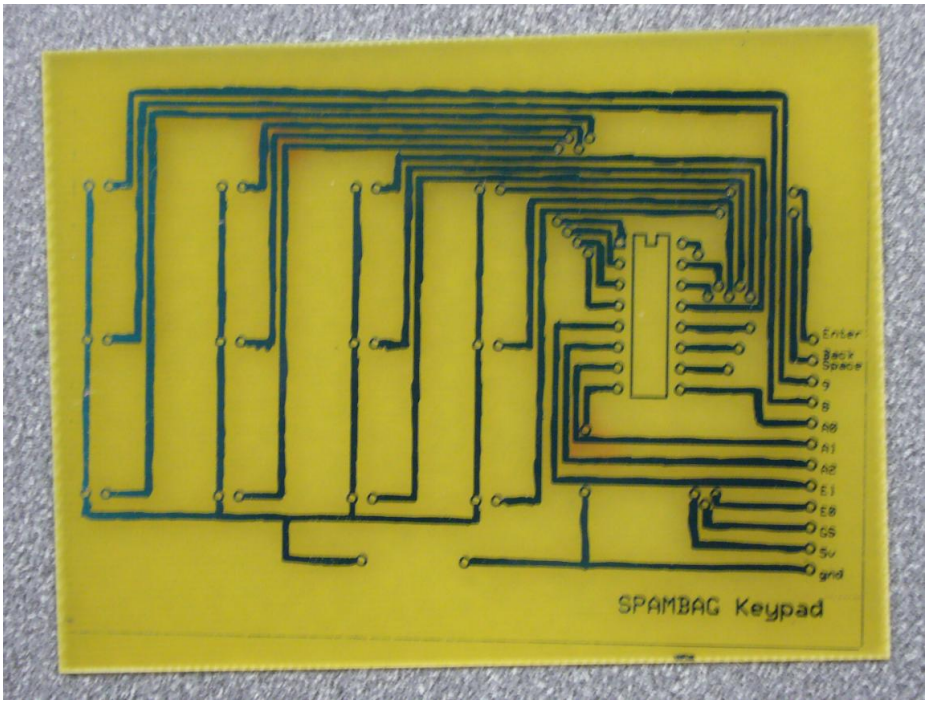


Figure 12 – Etched circuit board for the keypad

Fig. 13 below is a picture of the push buttons that will be used in the keypad. The circuit board will be placed in the electronics holder on the right with leads running into the electronics cover where the buttons will be attached. Twelve holes will be drilled into the cover and the buttons can be fit inside of them and the top screwed back on top. If the cover or buttons should ever need to be replaced, the buttons are easily removed by unscrewing the top and pulling the button out of the hold.

Figure 13 – Push button for keypad

Electromagnet

The electromagnet has had no change in design and is currently awaiting implementation. It still requires a fixture to attach to its head to allow it to interact with the balls better. Design considerations for that include drilling a small indentation into the head to create a small divot where the ball can rest or adding a small amount of solder to the head to create a ring where the ball cannot roll around on the head. Fig. 14 shows the electromagnet used in this project.

Figure 14 – Electromagnet used in this project

Frame Construction

Little modification has been done to the design of the frame. One or two small pieces have been removed from the motor carts because there was no good way to fasten them to the rest of the cart. The removal does not affect any performance of the motor carts. After creating the mock-up for the last report, the large size of the frame was apparent. Evidently, not all of the space allotted for electronics will be needed, but it has been left alone in case modifications need to be made later. The requirements specification states that the frame must stay within 1m x 1m x 1m ï which it has. The current dimensions are 28.25 inches (717.55 mm) wide by 24 inches (609.6 mm) deep by 16 inches (406.4 mm) tall.

The Plexiglas pieces for the frame are all cut out of their original sheets. All of the pieces are within 1/8 inches (3.175 mm) of their intended dimensions. All pieces small enough to fit into the vice on the milling machine have been machined to their intended sizes within 0.005 inches (0.127 mm) neglecting surface roughness. Such pieces include the longitudinal and latitudinal walls, the sides and top of the upper display, and the cross members. For larger pieces such as the base, the plan is to make a very light impression or score in the surface of the Plexiglas through the protective paper. It will not be enough to compromise the integrity of the base; it is only to mark where the actual edge will be. The walls will be attached using the score as a guide and after construction is complete, the overhang will be sanded off with very coarse sandpaper followed by finer grit or very carefully using a Dremel sander. Fig. 15 shows the completed motor carts without the stepper motors fixed to them so that the entire cart is visible.

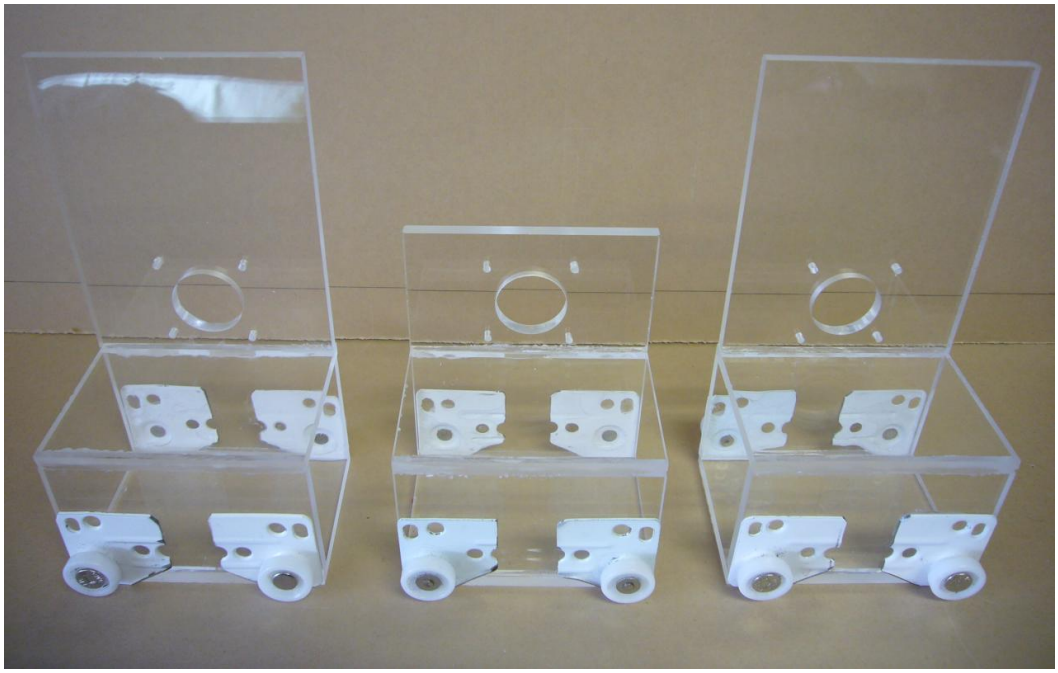


Figure 15 – Completed motor carts

The hoppers have undergone a very major design change in the last week due to an unforeseeable design flaw. Originally, when the hoppers were being designed, a switchback system was created. This design was tested by building a 1:1 scale model of the hoppers using cardboard because it was easy to use and obtain. The design worked well with the cardboard and it was assumed that because the Plexiglas was much smoother than the cardboard that the balls would roll even better. The hoppers were constructed and the design was tested. Unfortunately, the balls did not move as they had in the cardboard tests; in fact, they did not move at all. We believe this to be because there is a greater coefficient of static rolling friction between the chrome steel balls and the Plexiglas than between the chrome steel balls and the cardboard. It was only after the hopper was placed at about a 45° angle that they moved as originally expected. Because of its size and the boundary conditions, this was not permissible, so an improved design had to be created. Using the ñmissò hopper as it had been constructed, it was cut in half and made into a vertical hopper that will be glued to the front of the upper display on the lower right-hand corner. The hopper itself will hold about 40 balls. A track that can hold an additional 40-45 balls will come from the exit of the hopper that runs to the front of the frame over the top of the electronics cover. It will make a 90° turn and the end of the track will be about where the ball was to be picked up before. The trick with designing this is to ensure that the track does not interfere with the path of the cart for the movement system. The ñhitò balls will run along the same track as the ñmissò balls but separated by a thin divider. Because significantly less balls are needed for the ñhitsò, no hopper is required; only the track. The assembled ñmissò hopper can be seen below in Fig. 16.

Figure 16 – Hopper for the ñmissò balls

The method of fastening the frame together has changed slightly as well. Originally, the pieces were going to be superglued to make sure they are in the right spot and then sealed with silicone. After testing the strength of the superglue and the silicone, we have decided not to use silicone unless there is a great need. The test pieces that were superglued together were unable to be separated when subjected to tension, shear, or torsion. The superglue holds quite well and does not really need any extra help from the silicone on smaller sections. Since silicone is not greatly needed, we do not want to spend part of our budget unnecessarily. Because the silicone has already been bought and opened, we may use some on the ball return plate to cushion the fall and to help support the shock to the superglue holding it in place. 70 to 80 balls falling all at once on the ball return board could eventually take its toll.

Pieces of the frame such as the game board and front wall have been cut out, but the details of those pieces have not been added. Such details include cutting holes and slots. The holes need to be cut using the drill press and until recently, the drill press did not have a way to securely clamp the machined piece. Now that there is a clamp available, progress will be made to cut such details.

Motors

Due to the light weight of the motorcarts and the ship sensing system that the stepper motors are moving, only a very small amount of torque was needed. The important factor that the motors had to possess, however, was precision and repeatability. The easiest way to do this was to use stepper motors. After deciding on stepper motors, we decided on hybrid stepper motors because the angle per step was only 1.8° as opposed to the 7.5° - 15° of regular stepper motors. Using a pinion with a diameter of 0.9583 inches (24.342 mm) meant that we could control the movements to as small as 0.015 inches (0.38 mm). In addition, stepper motors possess the advantage of being significantly smaller and lighter than DC motors of the same torque output. Stepper motors have open loop control circuits so no controller is needed which makes using them significantly easier to use.

We originally purchased three RB-soy02 hybrid stepper motors from Robot Shop (www.robotshop.ca) but after re-evaluating the design, we decided it would be best to add a fourth stepper motor to aid in the longitudinal movements to avoid lagging. All four motors have been tested to ensure that all four electromagnets in each stepper motor are functioning properly. Figure 17 below shows the stepper motor we are using with a pinion attached.

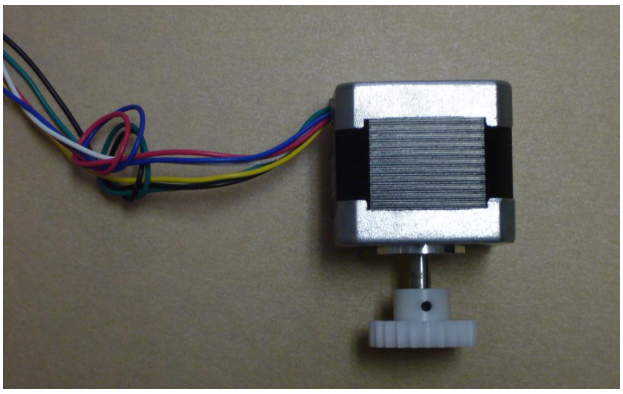


Figure 17 – Stepper motor with pinion attached

Each stepper motor being used is a six wire stepper motor. This means that it has one wire for each electromagnet inside the motor and two center wires that connect the electromagnets to complete the circuit. Each center wire will receive 2.5V and the other four wires receive 5V with 25mA signals from the microcontroller. Motor testing has revealed that not enough current was being sent from the microcontroller to adequately run the stepper motors. To fix this, we are using transistors as switches to allow or cutoff current flow from the microcontroller to account for the current deficiency. When the microcontroller sends a signal, current is allowed to flow; but, when no signal is sent, current is not allowed to flow. Because the number of pins on the microcontroller was a concern, the stepper motor on the right and the one on the left are receiving signals from the same four pins. Otherwise, eight pins would be required. However, the stepper motor on the right side of the movement system will be wired ñbackwardsò so that when one turns clockwise, the other will turn counter-clockwise and vice-versa. Since the shafts are facing one another, this will cause the motors to move the system in the same direction.

Steel Ball Bearings

The steel balls shown in Fig. 18 serve as the game pieces that mark the placement of the computerôs move. They were ordered from McMaster-Carr because that company sold steel ball bearings in the small number we needed. The material was chosen to be E52100 chromium steel because of its magnetic properties and its resistance to corrosion and oxidation.

Tests have been performed with the steel balls and the electromagnet to determine how much voltage and current are needed to attract the ball but not attract other balls with it. Nearer to the completion of the project, the balls will be lightly sanded to help the spray paint adhere and then spray painted red and green to symbolize hit or miss respectively. There is a slight concern that sanding may remove a small amount of the chromium on the steel balls which would decrease the magnetism. This will be accounted for by using magnetic spray paint.

Figure 18 – Steel ball bearings used as markers

Ship Sensor Design

Two different sets of rails were being considered for the push button sensing system. The first set of rails are standard kitchen drawer rails as shown in Fig. 19. The advantage of these rails is their light weight. Light-weight is desirable since a lot of weight could cause a lag on the movement of the motor in one direction. Also, they fit perfectly in the space requirements of our original design. The rails would need to be machined, since the minimum length in which they are manufactured is 12 inches (30.48 cm). A major disadvantage for using this rail system is the difficulty of attaching the gear rack to the rail; an additional lubricant will be needed to decrease friction with that specific model of rails. Also, an extra set of wheels would be needed to ensure that the gear rack could be moved easily along the whole rail. In addition, Plexiglas pieces will need to be incorporated to successfully attach the gear rack onto the rails.

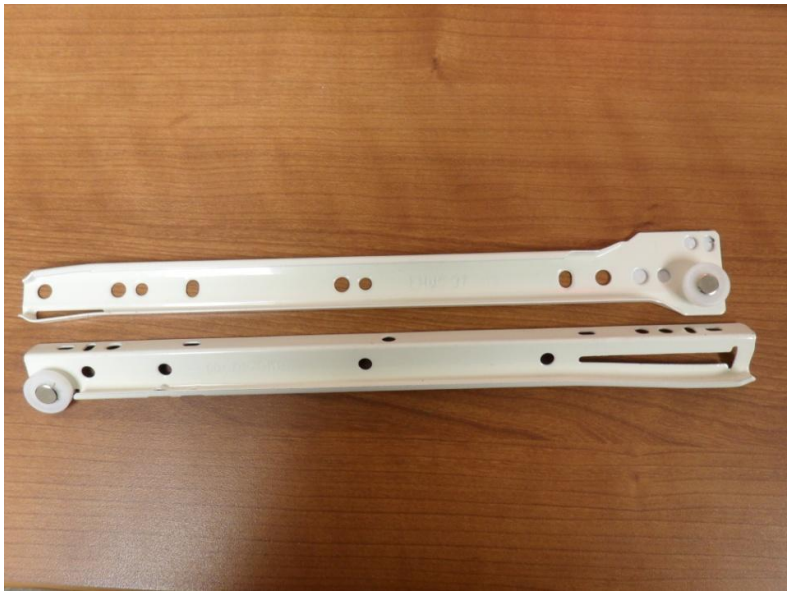


Figure 19 - Standard Kitchen Drawer Rails.

The second set of rails considered are telescopic rails seen in Fig. 20. These rails are heavier than the other set of rails which could affect the linear movement produced by the motors. They also come in 12 inch (30.48 cm) lengths and would need to be machined. Also, these rails are bigger than the expected size, so the space requirements of the original design would need to be modified. The advantage of using these rails is that no additional wheels need to be incorporated to attach the rail to the gear rack. Since telescopic rails operate will ball bearings, no additional lubricant would be needed to reduce friction. For the way the rail is designed, the gear would need to support a portion of the weight of the rail. However, it was shown in the gear calculations that the gear teeth will be able to handle roughly four times the maximum load exerted by the stepper motorôs shaft. The factors of safety are the same as the ones calculated for the initial design.

Figure 20 - Telescopic Rails

The rails chosen for the sensing system design are the telescopic rails mainly for the ease of attachment between the gear rack and the rail. To overcome the weight factor mentioned above, the rails were cut using a horizontal band saw, as shown in Fig. 21, and the outer part of the rail was removed. The finished product is displayed in Fig. 22.

Figure 21 – Cutting of rails

Figure 22 – Rails cut to size

Other than the consideration of an alternative set of rails that will be used for the ship sensor, the sensing system design has not changed. The system will still consist of a set of rails, two gear racks, and a gear. The electromagnet will be attached to the end of one rack, and the push button will be attached to the end of the other rack as shown in Fig. 23.

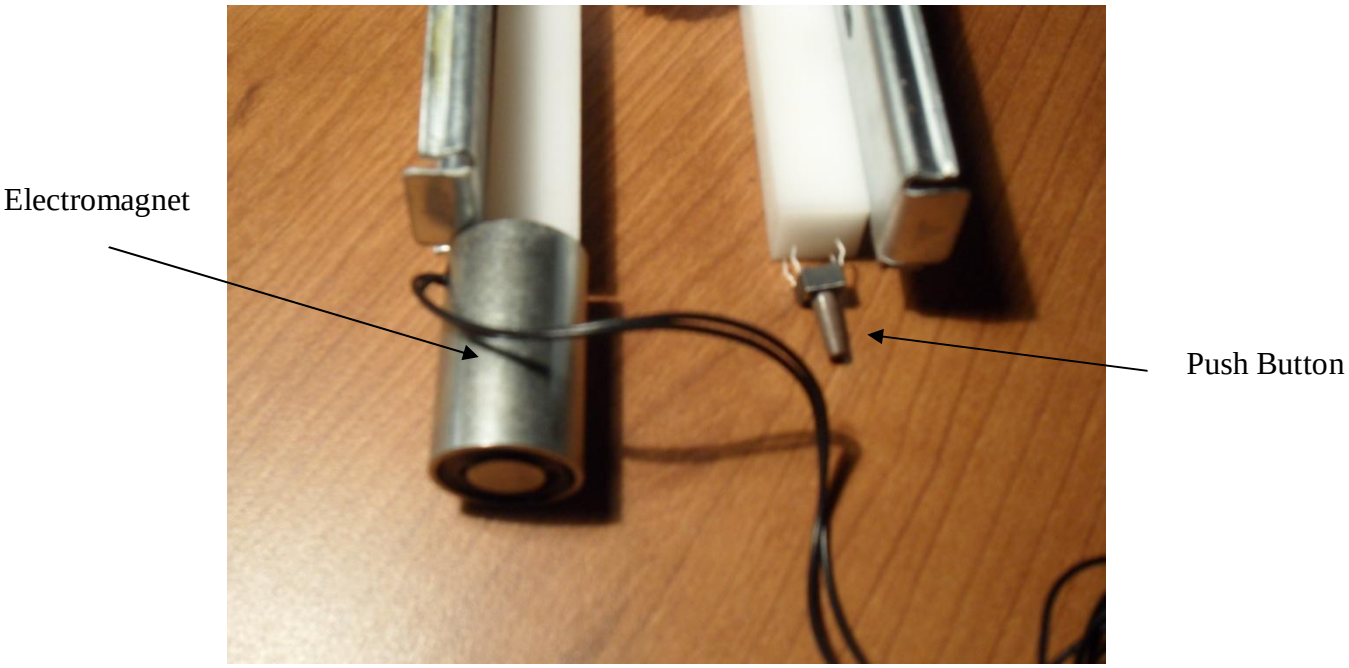
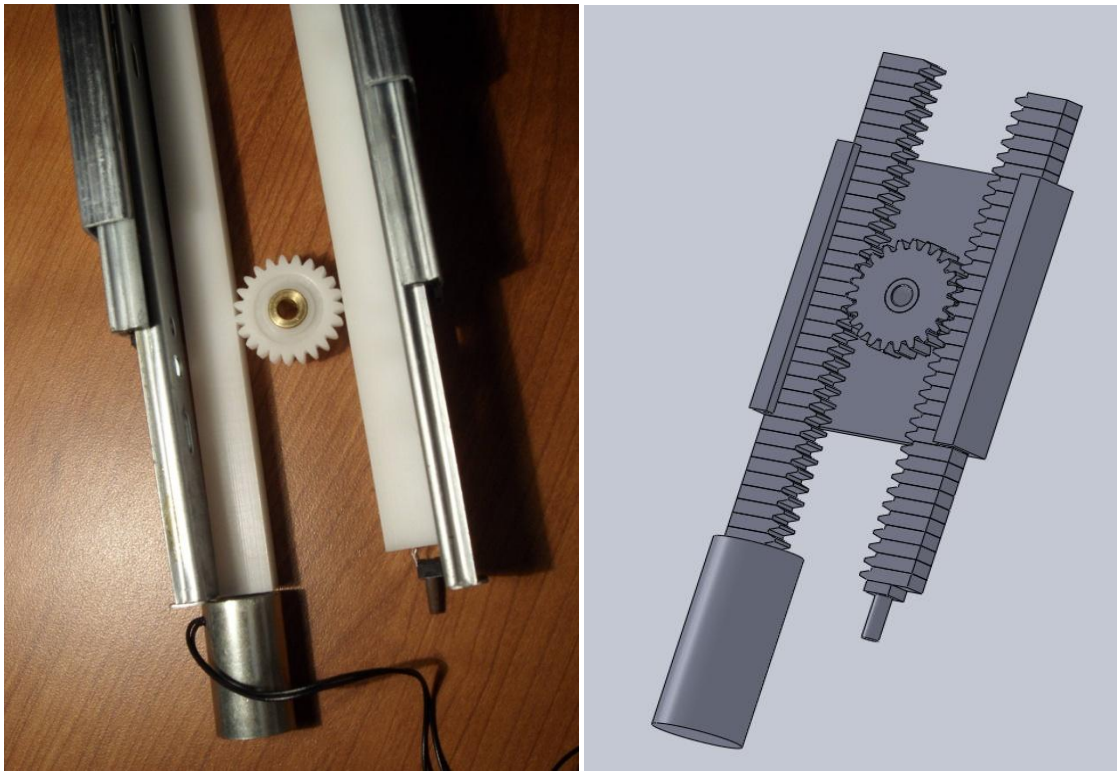


Figure 23 – Electromagnet and push button incorporated into sensing system

All of the parts needed for the sensing system have been purchased. Currently, progress regarding system assembly and testing have been hindered due to the problems that have been experienced with the CNC machine for the fabrication of the gear rack pieces. The gear racksô components interact will all of the other parts of the system; thus, they have not been attached. The similarity between the original design and the actual sensor are shown in Fig. 24.



(a) (b)

Figure 24 - Ship Sensor System (a) Assembly (b) SolidWorks model.

The spatial distribution of the different components that are integrated into the sensing system for final assembly was determined based on the width of the rails, the height of the gear racks, and the diameter of the gears purchased. A SolidWorks drawing was made to represent the locations of each of the components on the Plexiglas piece (2.5in. x 2.5in.) that is attached to the crossmember cart. The final design is shown in Fig. 25.

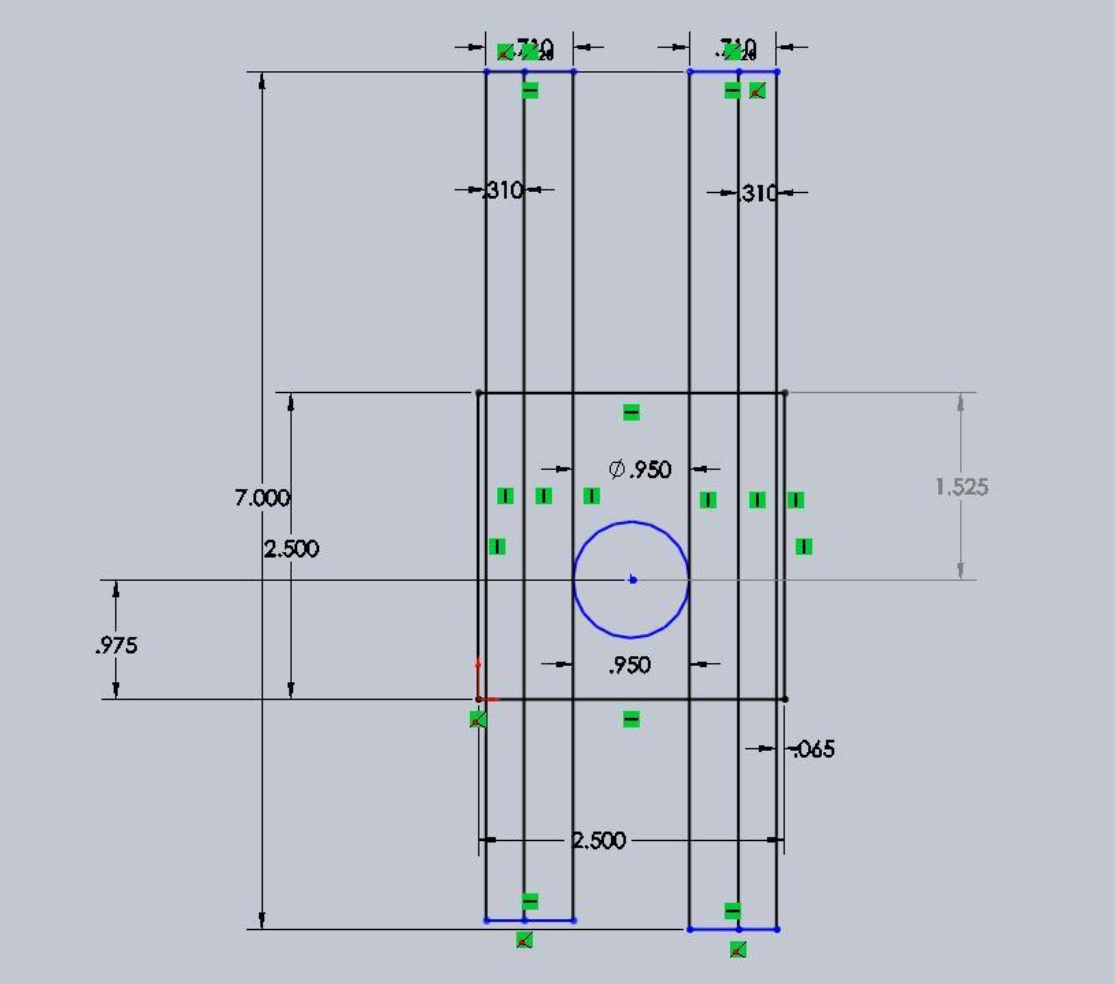


Figure 25 – Final design of sensing system with dimensions.

Gears

The four gears needed were purchased according to the requirements specification stated in the Final Design Report and are shown in Fig. 26. Since the gears were purchased in English units, the bore size was selected to be the closest to the diameter of the stepper motorôs shaft which is 5 mm (0.1969 in.). The actual bore size of the gears was 0.1875 in. (4.7625mm), which is a difference of 0.0094 in. (0.23876mm). The centers of the gears were successfully bored out to fit the shaft dimensions. It was shown that using the set screw, the gears were securely attached to the stepper motorôs shaft as shown in Fig. 27. The design of a set screw is such that the gear is guaranteed to stay in place. To ensure this further, we will lightly sand a very small section of the shaft to increase friction between the shaft and the set screw.

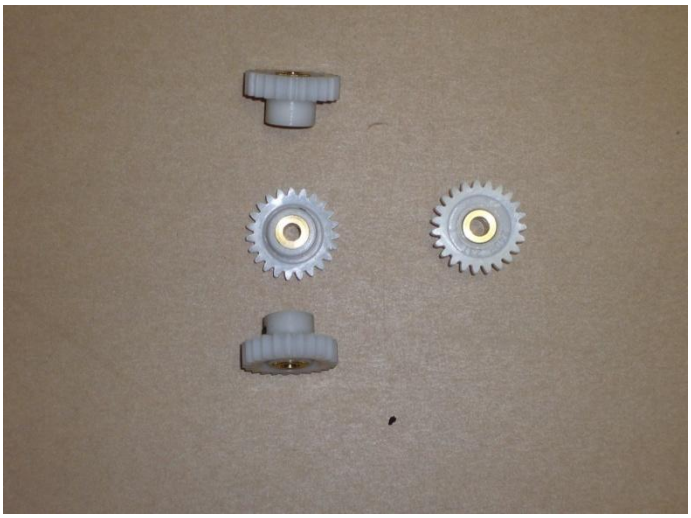


Figure 26 - Actual gears purchased.

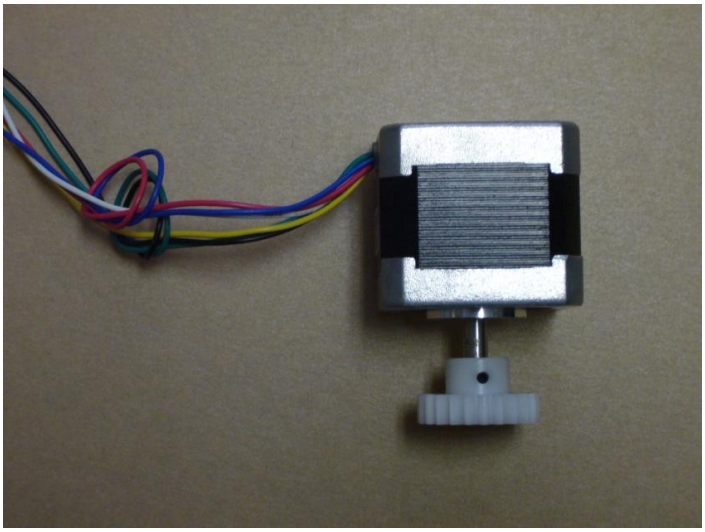


Figure 27 - Gears securely attached to the stepper motorôs shaft

Racks

Another modification to the original design is the material selected for the gear racks. Two different types of plastic bars were purchased. Instead of Nylon 101, acetal (Delrin) and PVC Type 1 were purchased. This modification was because of the availability on the market and the cost of the bars in the dimensions that were needed. Even though Delrin has a lower yield strength compared to Nylon 101, no additional gear calculations are needed since the previous gear calculations were made using Delrin.

For the fabrication of the gear racks, a CNC program was written using free software downloaded (CNC Simulator) from www.cncsimulator.com. This software could be used for non-machine specific simulations. The simulation offers a three-dimensional and a two-dimensional simulation at the same time. In this program, the tool position, tool number, and machining time are specified.

The tool that is being used in the CNC machine to cut the racks is very small (0.03125in.) (0.79375mm) because of the size restrictions the tooth profile creates. The number of lines of code to make a small movement increased dramatically to ensure that the tool does not break. The trimetric view of the tool movement is shown in Fig 28. Even when the dimensions of the plastic bars are small (18 in. x 0.5 in. x 0.5 in.) (45.72mm x 1.27mm x 1.27mm), the desired output of the tool needs to be divided into a lot of small intervals.

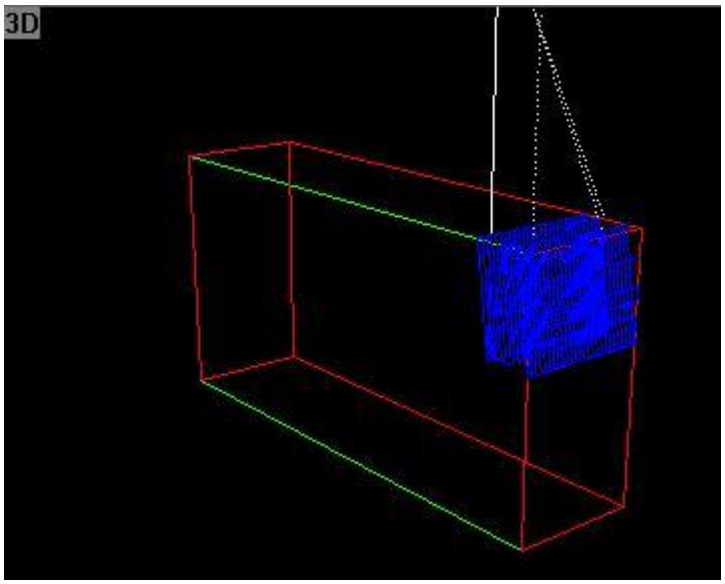
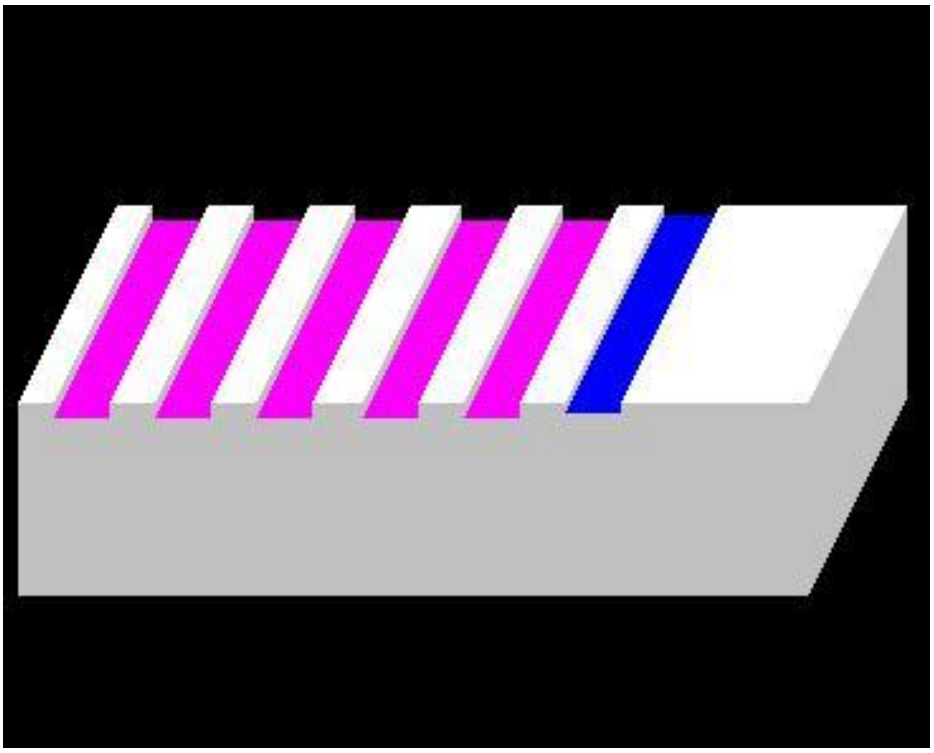


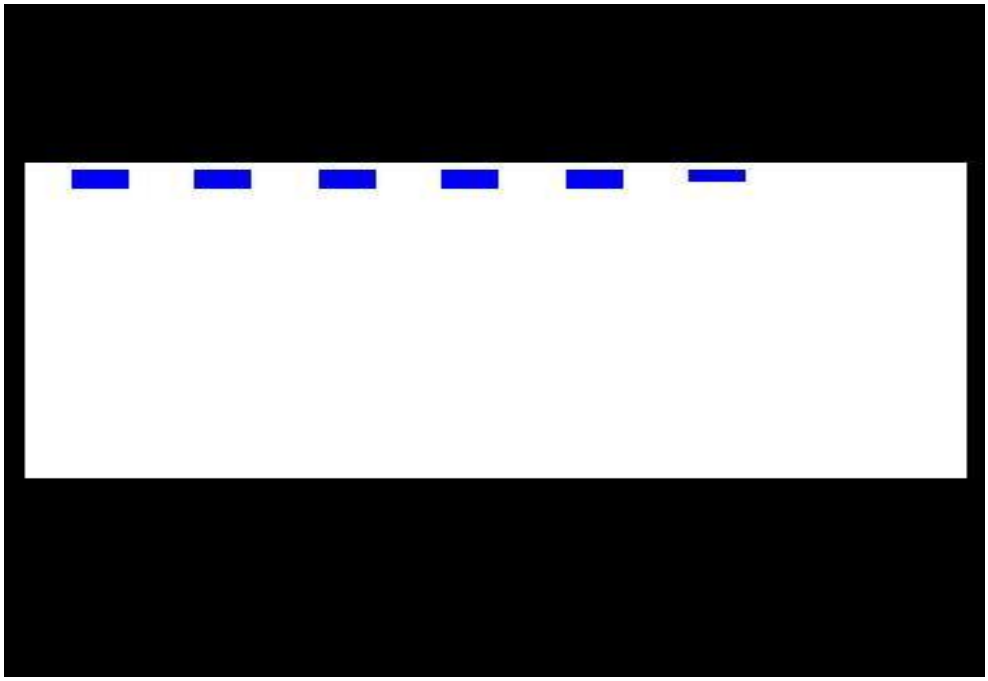
Figure 28 – Trimetric view of the tool-movement

The movement of the tool for the outer edge of the tooth profile is solely in the Y and Z directions. The inclination of the tooth profile is given by a change in the X. There is an alternation between G00 mode and G01. G00 is a rapid transverse mode that moves the axes to a location with a rapid feed rate. It is used for tool movements were no material needs to be cut. G01 is a linear interpolation mode which adjusts the velocity of the movement to allow material to be cut.

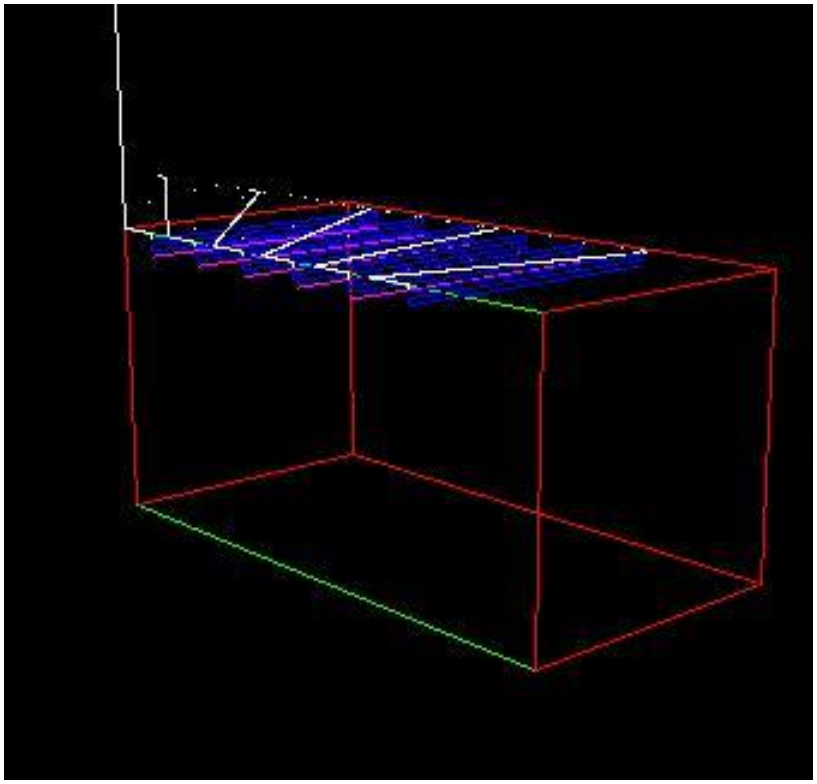
The CNC programming is complete and the code for a single tooth profile can be viewed in Appendix C. The tooth profile was programmed based on the dimensions available at the Urley Laboratory. Two different programs were developed to cut the teeth. The first program uses two different tools. The first is a 0.0625in (1.5875mm) diameter tool to cut straight lines and remove an initial amount of plastic as shown in Fig. 29. The second part of the program uses a 0.03125in (0.79375mm) diameter tool in which the ñVò shape of the tooth is done with two different passes to avoid the tool being broken. This process is shown below in Fig. 30. The advantage of this program is the significant reduction in the time needed to cut every tooth. The disadvantage is that additional time is needed to change the tool in the machine and to zero the coordinates to accurately match the two cuts to form the tooth profile. The tools used are shown in Fig 31.



(a)

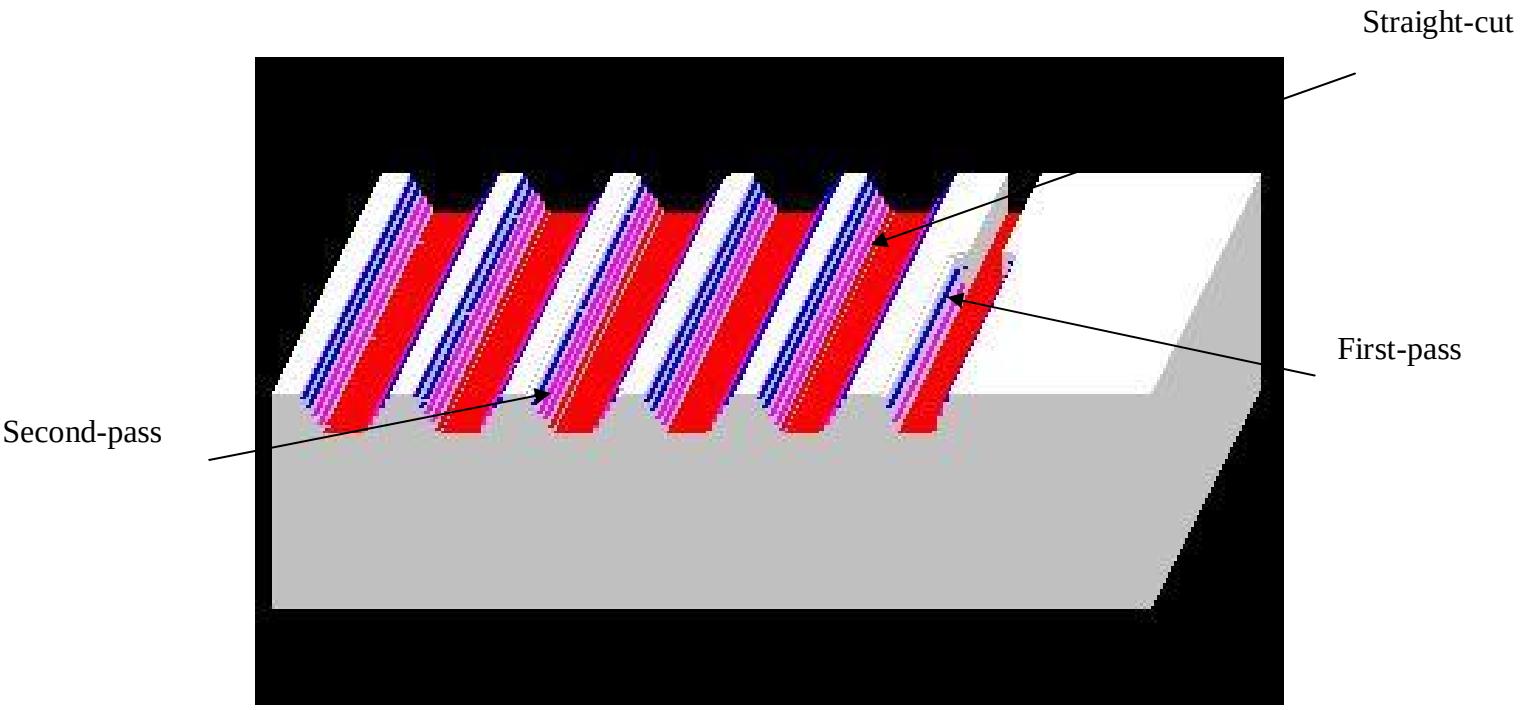


(b)

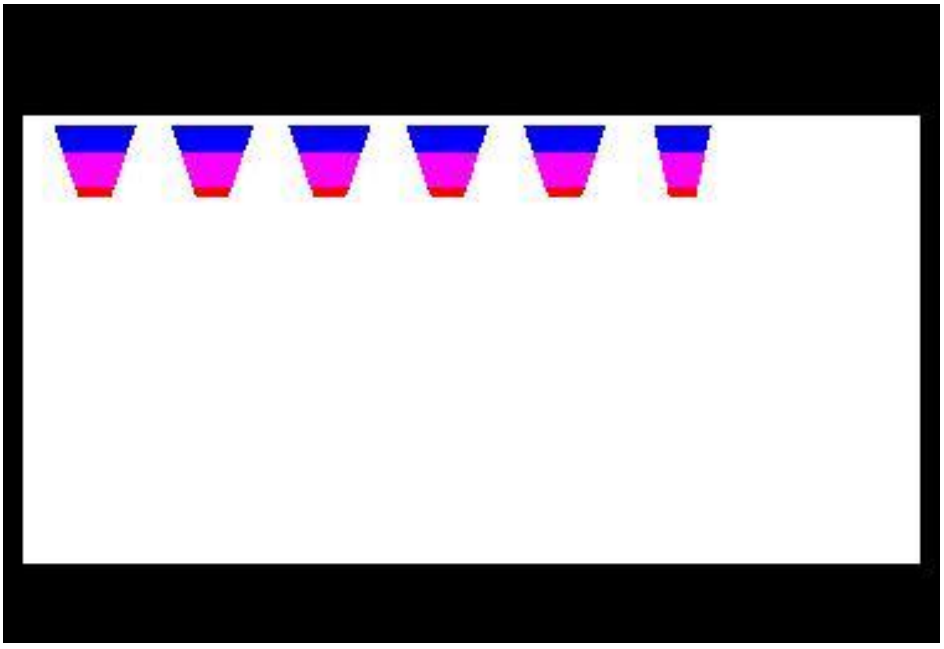


(c)

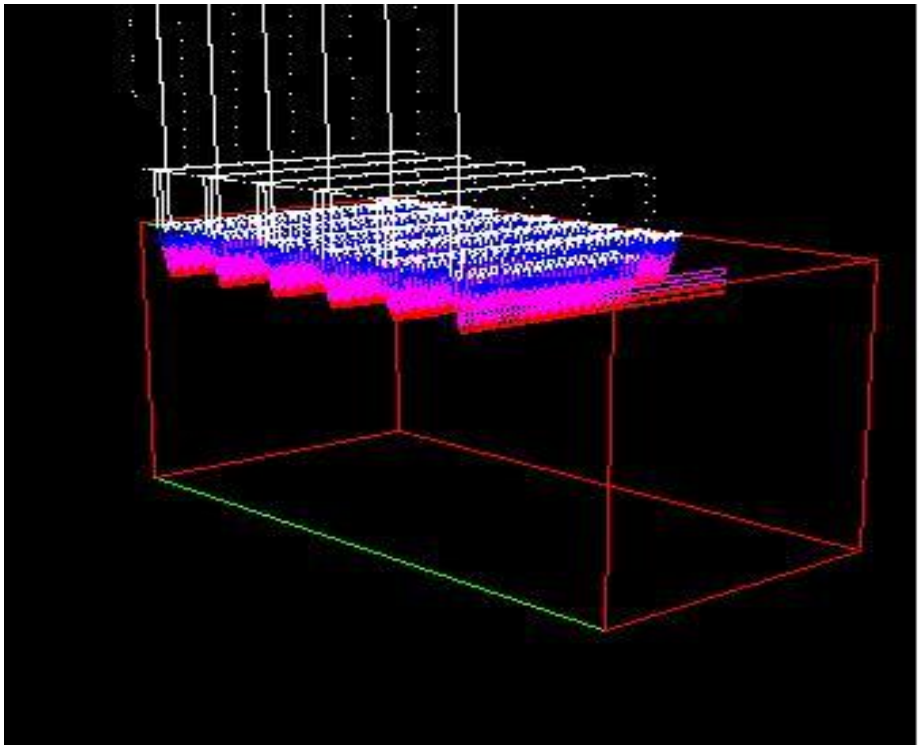
Figure 29 – (a) Block-view (b) XZ plane of the block (c) 3-D model of the CNC programming using the 0.0625 in (1.5875 mm) tool.



(a)



(b)



(c)

Figure 30 – (a) Block-view (b) XZ plane of the block (c) 3-D model of the CNC programming using the 0.03125 in (0.7938 mm) tool.

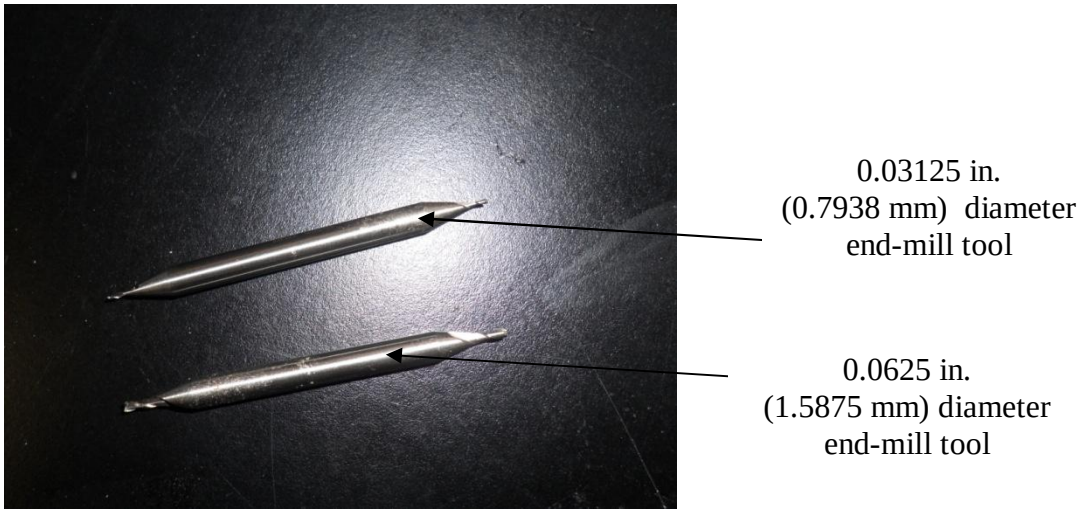


Figure 31 – Tools used to cut the gear racks.

Preliminary testing was done using the first program. PVC Type 1 was used to test the code on the CNC machine as shown in Fig. 32. The tooth was successfully cut with a good surface finish. The second program was developed using the smaller tool that does the straight cut and the ñVò shape. It is the fastest way to cut the tooth profile since it avoids the tool being changed and eliminates the error produced by the alignment of the smaller tool with the cut done with the larger tool.

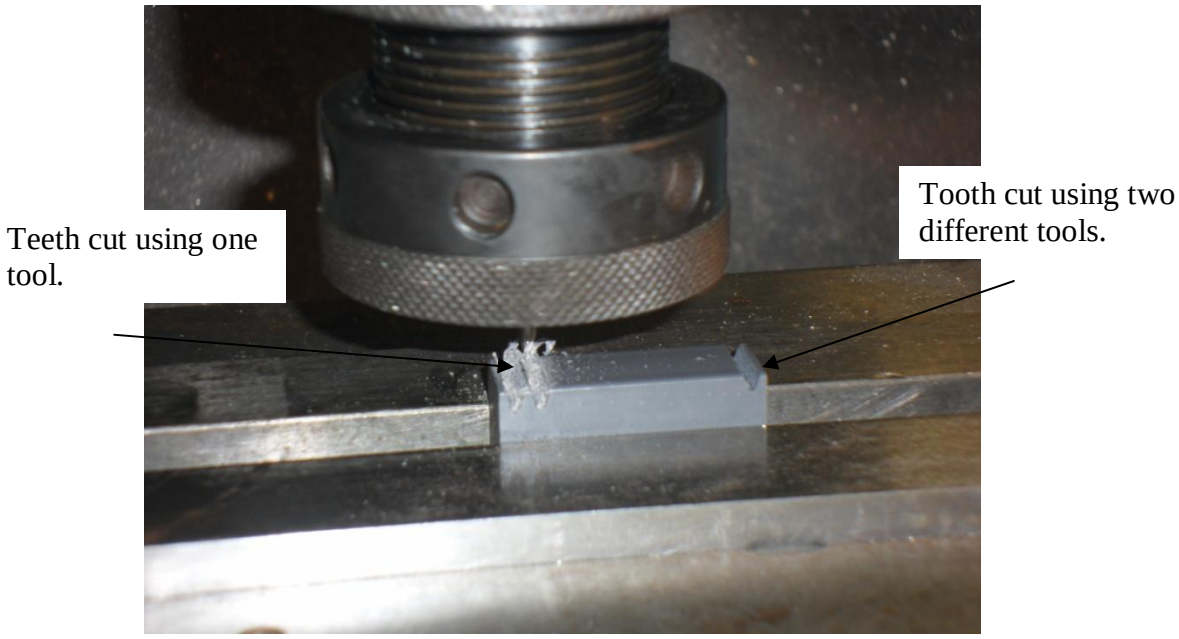


Figure 32 – Experimental cutting of teeth using two different CNC programs. Material used is PVC Type 1.

In Fig 33, it can be seen that for the teeth cut using one tool, the plastic melted and even when the tooth profile was done correctly, the surface finish was poor. This was mostly due to the fact that the cutting speed was too high, the feed rate was too high, and the tool became hot.

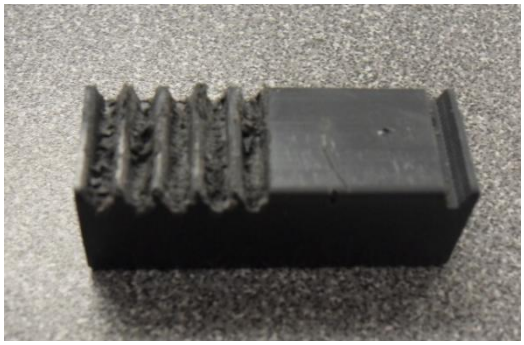


Figure 33 – Experimental cutting of teeth using two different CNC programs. (PVC Type 1)

From the experimentation using PVC Type 1, it was determined that the teeth needed to be cut using the program that incorporated two different tool sizes. To determine the settings for cleanest cut of the teeth, the feed rate and spindle speed were altered separately. Since these settings would be used to cut the actual racks, we decided to perform the tests using Delrin. Six different teeth were cut using the combinations of feed rate and spindle speed specified in Table 3. The results can be seen in Fig. 34.

Table 3: Testing used for the experimentation using Delrin

Tooth Number	Feed Rate (in./min)	Spindle Speed (rev/min)
1	1	1000
2	1	2000
3	1	3000
4	2	1000
5	2	2000
6	2	3000

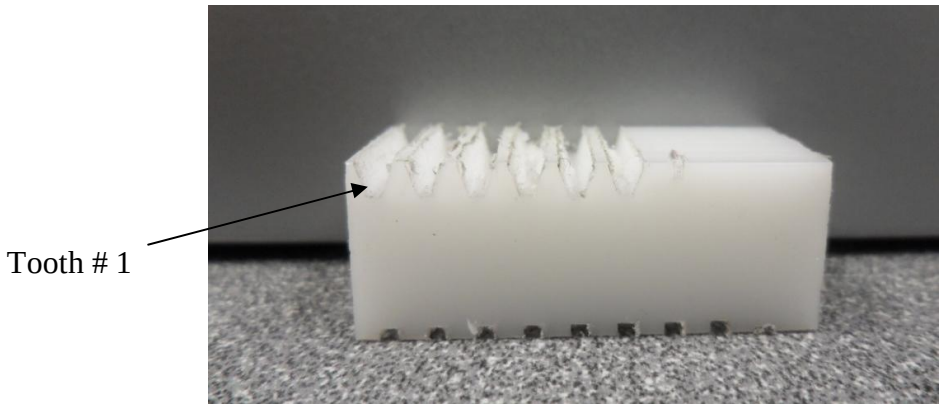


Figure 34 – Testing results using Delrin with different feed rates and spindle speeds.

It was determined that the best tooth cut was done using the lowest feed rate and the lowest spindle speed. At higher feed rates and spindle speeds, the plastic started melting and produced an accumulation of melted plastic inside the cut as was seen in Fig. 33. The disadvantage of this combination of feed rate and spindle speed is the time needed to complete the cuts. Using this combination, the average time needed to cut one inch of material is approximately 2 hours. The parts needed for the project are 3 racks of 18 inches (45.72 cm) each and 2 racks of 7 inches (17.78 cm) each. The total time required to cut all the racks needed is

approximately 136 hours without taking into account the time delay produced by the changing of the tool. Through the preliminary testing, it was confirmed that the programming was done with the right dimensions. The cut teeth meshed correctly with the purchased gears as shown in Fig. 35.

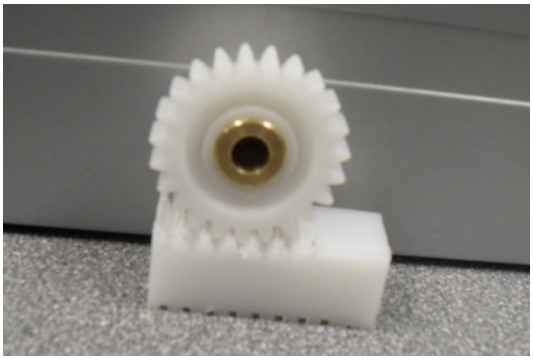


Figure 35 – Meshing of the gear and cut teeth on the rack

Alternate Design

Due to the problems we are facing with being able to successfully cut the racks in a timely manner, an alternate design is being considered as a potential backup. The major roadblock right now is that without the gear racks ready, the construction of the frame and the ship sensor design are delayed. These two modules of the project are of great importance as they constitute the biggest part of the project. One potential option we are considering is purchasing metric gears and racks to avoid the fabrication of the gear racks. The major disadvantage would be the budget that it would consume.

The gear analysis was done using English units. However, most gear equations that are used for English gears are equally applicable to metric gears if the module ómô is substituted for diametral pitch. The relationship between diametral pitch and module is shown in Eq. 1, where m is the module and P_d is the diametral pitch.

$$m = \frac{25.4}{P_d} \quad (1)$$

In our previous design, the diametral pitch chosen was 24 DP, so after converting the diametral pitch, the module is approximately 1. For this reason, gears and gear racks with a module of 1 were chosen. The material, style, quality, and pressure angle were the same as the ones selected before. The gear calculations were computed again to make sure the alternative gear and rack selection will handle the stresses produced by the movement and ship sensor system. These calculations can be viewed in Appendix D. A SolidWorks sketch of the gear is shown in Fig. 36.

Gear Specifications

Manufacturer: Stock Drive Products Sterling Instruments SDP/SI

Part Number: A 1Z 2MYZ1002405

Unit: Metric

Module: 1

No. Of Teeth: 24

Material: Acetal - Brass insert

Style: Pin Hub ï with Set Screw

Quality: Class Commercial ï Molded-

Bore Size: 5 mm

Pressure Angle: 20°

Face Width: 9 mm

Pitch Dia.: 24 mm

Hub Dia.: 15 mm

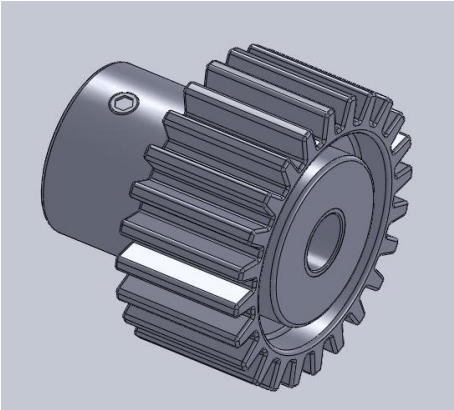


Figure 36 – Alternative Metric Gear

Rack Specifications

Part Number: A 1M12MYZ1025

Module: 1

Pressure Angle: 20°

Material: Acetal Molded

Quality Class: ISO 8 (AGMA Q9)

Stock Length: 250 mm

Face Width: 9 mm

Height: 9 mm

Pitch Height: 8 mm

Budget Analysis

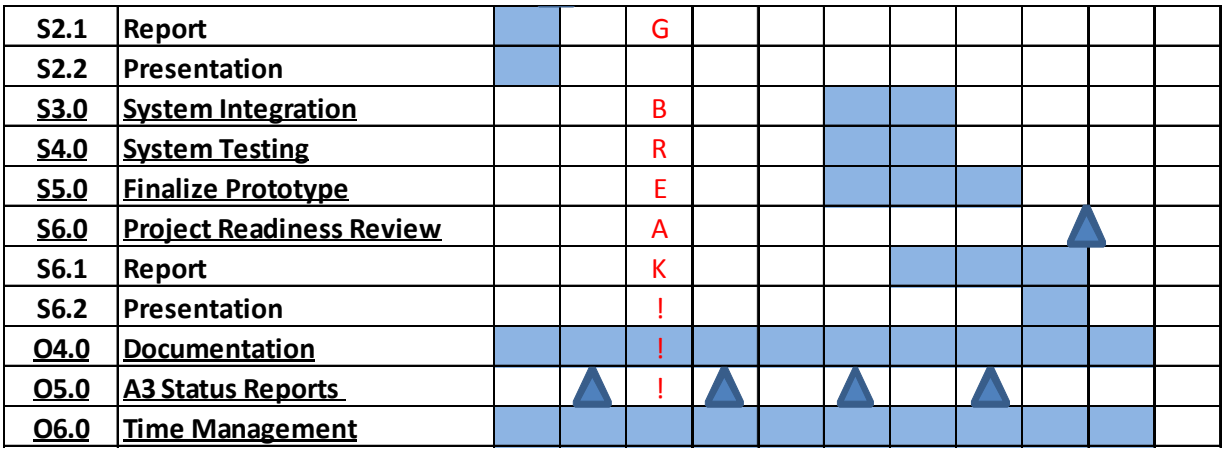
Item	Spent
Push Button for Ship Sensor	$9.15
Steel Balls	$33.77
Motors	$96.56
LCD Screen	$24.41
LEDs	$33.00
Electromagnet	$37.21
Movement Rails	$14.52
Gears	$32.96
Ship Sensor Rails	$9.67
PVC Type 1	$3.90
Quad SR Latches	$47.00
Quad 2 Input NAND Gates	$8.92
Push Buttons for Keypad	$11.80
Plexiglas	$165.22
Binding	$2.00
Delrin Bars	$32.50
Silicone and Superglue	$8.33
Diodes, Demultiplexors,Voltage Regulators	$17.96
Superglue	$14.04
Transformer and Transistors	$30.00
	$632.92

Unpurchased Items	Estimated Cost
Professional Etching Board	$100.00
Schmart Board	$10.00
Small Circuit Supplies	$15.00
	$125.00

Actual costs and anticipated costs match the budget well. We have purchased $633 and still have to purchase approximately $125 of supplies. This $125 is for a dual layer professional PCB, a Schmart Board, and small circuit components. Out of the total of $850 that we are allowed to spend, we expect to spend $758, but will probably have a few small things such as a little extra PCB cost or a few extra resistors which will put out total around $780. This is approximately 92% of our allotted budget leaving 8% or $70 for anything we have missed.

Schedule Analysis

Tasks		Feb	March				April				May	
		28	7	14	21	28	4	11	18	25	2	9
S 1.0	**Parts Assembly and Testing**			S								
S1.1	**Frame Construction**			P								
S1.1.1	Finish Milling to Size			R								
S1.1.2	Assemble Hoppers			I								
S1.1.3	Rails andWalls			N								
S1.1.4	Upper Display			G								
S1.1.5	Movement System											
S1.1.6	Game Boards			B								
S1.1.7	Remaining Walls and Covers			R								
S1.2	**Ship Sensing System**			E								
S1.2.1	Finish Design and Code			A								
S1.2.2	Cut Racks			K								
S1.2.3	Make Ship Pieces			!								
S1.2.4	Assemble System			!								
S1.2.5	Individual Testing			!								
S1.3	**LED**											
S1.3.1	Design PCB			S								
S1.3.2	Send For Etching			P								
S1.3.3	Assembly			R								
S1.3.4	Individual Testing			I								
S1.4	**LCD**			N								
S1.4.1	Individual Testing			G								
S1.5	**Keypad**											
S1.5.1	Etch Board			B								
S1.5.2	Assemble Keypad Elements			R								
S1.5.3	Individual Testing			E								
S1.6	**Power Supply**			A								
S1.6.1	Fix Motor Current Issue			K								
S1.6.2	Redesign Power Supply			!								
S1.6.3	Breadboard Circuit & Test			!								
S1.6.4	Etch board			!								
S1.6.5	Assemble Power Supply											
S1.6.6	Individual Testing			S								
S1.7	**Microcontroller**			P								
S1.7.1	Write code			R								
S1.7.2	Write Test Code			I								
S2.0	**Midterm Progress Report**			N								



The schedule above is our updated schedule. The old schedule was created at the beginning of the project and some components of the project have been removed while others have been altered tremendously. Also, because we had been set back due to the complexity of the LED PCB design and the gear rack fabrication, those parts of the schedule needed to be revised. This new schedule will keep us on track much better and we can reference it weekly to see exactly what needs to be done. The previous schedule merely had the duration of each whole module, but this new schedule has a breakdown of tasks that need to be completed within each module.

Because we have just revised the schedule, we are completely on schedule. We should have about three weeks to have all of the finished modules implemented, tested and debugged. They will have all been individually tested so it is merely a matter of getting each module to work with every other module. We are sure that we can have our prototype completed and fully functioning as described in the Requirements Specification by the end of April.